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LAKE MEMPHREMAGOG STATE OF VERMONT, U.S.A., AND THE PROVINCE OF QUEBEC, CANADA

Pacific Northwest Environmental Research Laboratory

Prepared for:

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16. ABSTRACT
Annual total phosphorus and total nitrogen loadings to the lake were estimated and subdivded according to either point or non-point source origin. An assessment of the lake's trophic condition and limiting nutrient is also provided. All data collected by the U.S.E.P.A. National Eutrophication Survey during the one year study of the lake and its tributaries are included in the report.

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REPORT
ON
LAKE MEMPHREMAGOG
STATE OF VERMONT, U. S. A.,
AND
THE PROVINCE OF QUEBEC, CANADA

EPA REGION I

WORKING PAPER No. 19

WITH THE COOPERATION OF THE

VERMONT AGENCY OF ENVIRONMENTAL CONSERVATION

AND THE

VERMONT NATIONAL GUARD

AUGUST, 1974

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FOREWORD

The National Eutrophication Survey was initiated in 1972 as a research project in response to an Administration commitment to investigate the nationwide threat of accelerated eutrophication to fresh water lakes and reservoirs.

OBJECTIVES

The Survey was designed to develop, in conjunction with state environmental agencies, information on nutrient sources, concentrations, and impact on selected freshwater lakes as a basis for formulating comprehensive and coordinated national, regional, and state management practices relating to point-source discharge reduction and non-point source pollution abatement in lake watersheds.

ANALYTIC APPROACH

The mathematical and statistical procedures selected for the Survey's eutrophication analysis are based on related concepts that:

a. A generalized representation or model relating sources, concentrations, and impacts can be constructed.

b. By applying measurements of relevant parameters associated with lake degradation, the generalized model can be transformed into an operational representation of a lake, its drainage basin, and related nutrients.

c. With such a transformation, an assessment of the potential for eutrophication control can be made.

LAKE ANALYSIS

In this report, the first stage of evaluation of lake and watershed data collected from the study lake and its drainage basin is documented. The report is formatted to provide state environmental agencies with specific information for basin planning [§303(e)], water quality criteria/standards review [§303(c)], clean lakes [§314(a,b)], and water quality monitoring [§106 and §305(b)] activities mandated by the Federal Water Pollution Control Act Amendments of 1972.

Beyond the single lake analysis, broader-based correlations between nutrient concentrations (and loading) and trophic condition are being made to advance the rationale and data base for refinement of nutrient water-quality criteria for the Nation's freshwater lakes. Likewise, multivariate evaluations for the relationships between land use, nutrient export, and trophic condition, by lake class or use, are being developed to assist in the formulation of planning guidelines and policies by EPA and to augment plans implementation by the states.

ACKNOWLEDGMENT

The staff of the National Eutrophication Survey (Office of Research & Development, U. S. Environmental Protection Agency) expresses sincere appreciation to the Vermont Agency of Environmental Conservation for professional involvement and to the Vermont National Guard for conduct of the tributary sampling phase of the Survey.

Martin L. Johnson, Secretary of the Vermont Agency of Environmental Conservation; Gordon R. Ryper, Commissioner of the Water Quality Division; David L. Clough, Director, James W. Morse II, Biologist, and Wally McLean, Sanitary Engineer, of the Water Quality Division, provided invaluable lake documentation and counsel during the study. Reginald A. LaRosa, Director of the Water Supply and Pollution Control Division, and James F. Agan, Chief of the Operations Section, Environmental Engineering Division, were most helpful in arranging for the sampling of wastewater treatment plants involved in the Survey.

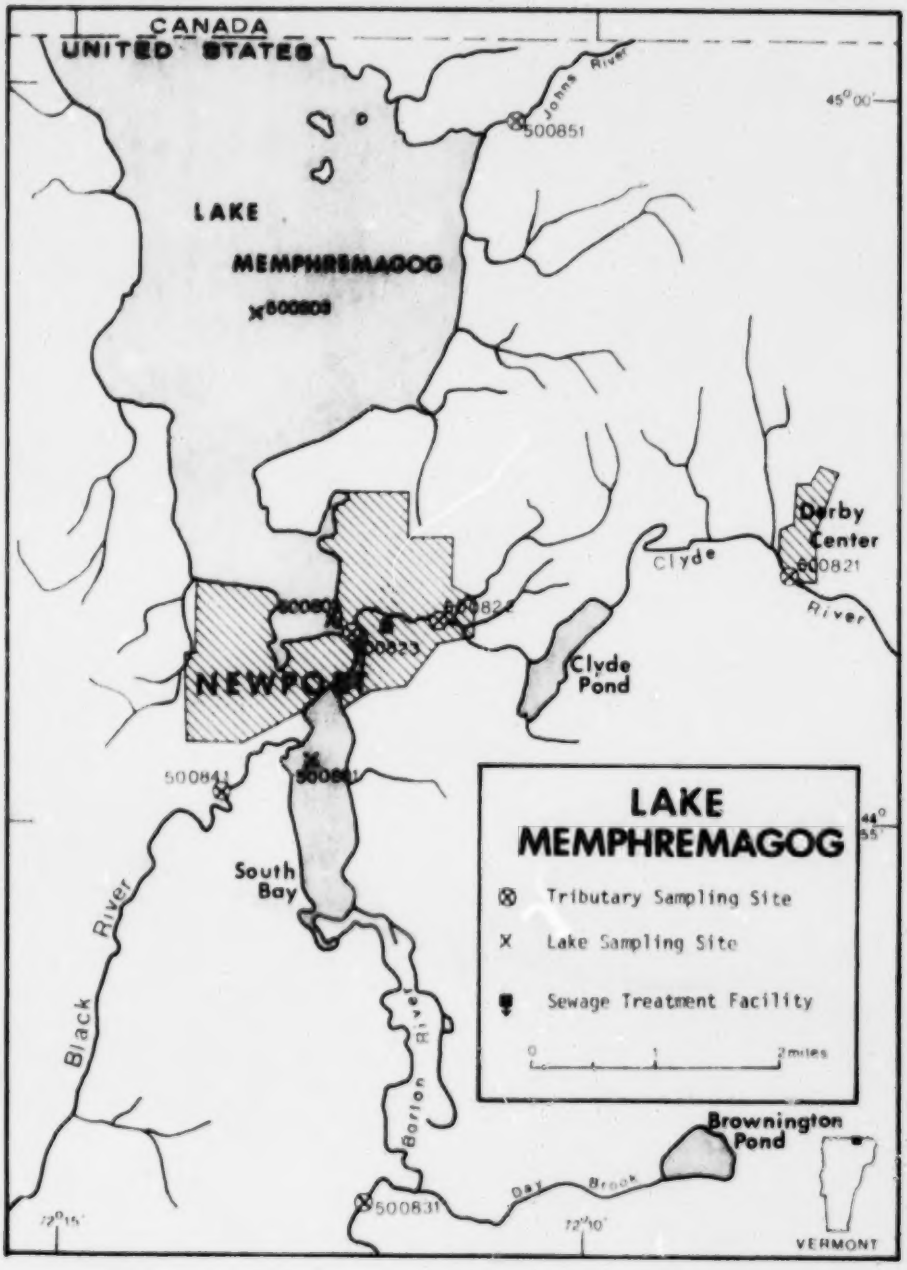
Major General Reginald M. Cram, the Adjutant General of Vermont, and Project Officer Major Howard Buxton, who directed the volunteer efforts of the Vermont National Guardsmen, are also gratefully acknowledged for their assistance to the Survey.

NATIONAL EUTROPHICATION SURVEY

STUDY LAKES

STATE OF VERMONT

LAKE NAME	COUNTY
Arrowhead Mountain Lake	Chittenden, Franklin
Clyde Pond	Orleans
Harriman Reservoir	Windham
Lake Champlain	Addison, Chittenden, Franklin
Lake Lamoille	Lamoille
Lake Memphremagog	Orleans
Waterbury Reservoir	Washington, Lamoille


CANADA
UNITED STATES
45°00'
500851
LAKE
MEMPHREMAGOG
500823
NEWPORT
Clyde
River
Derby
Center
500821
Clyde
Pond
500841
South
Bay
Black River
Barton River
Brownington
Pond
Oat Brook
500831
72°15'
72°10'
44°
55'
VERMONT
LAKE
MEMPHREMAGOG
Tributary Sampling Site
Lake Sampling Site
Sewage Treatment Facility
0
1
2miles

LAKE MEMPHREMAGOG*

STORET NO. 5008

I. CONCLUSIONS

A. Trophic Condition:

Lake Memphremagog exhibits progressive improvement in trophic condition from the south (Vermont) end to the north (Quebec) end. Survey data and data from previous studies indicate the Vermont portion of the lake is eutrophic, while at least the north half of the lake is as yet oligotrophic with a mesotrophic zone of transition presumably occurring between the two extremes.

Troublesome blue-green algae blooms have been increasingly frequent in the Vermont portion during the past few years, and a general deterioration of water quality has been noted; rooted aquatic vegetation is quite sparse in the main lake and approaches nuisance levels only in South Bay, Vermont, and Fitch Bay, Quebec (Clough, 1973).

B. Rate-Limiting Nutrient:

The results of the algal assay show that the Vermont portion of Lake Memphremagog was phosphorus limited at the time the sample was collected in May, 1973 (see page 8).

The 1972 lake data indicate phosphorus limitation in June but nitrogen limitation in July and October of that year. Some may question point-source phosphorus control when the lake may be

* A table of factors for conversion of English units to metric equivalents is given in Appendix D of this report.

nitrogen limited at times; note, however, that even in October, 1972, when the N/P ratio was 7/1, a reduction in mean dissolved phosphorus of only 6 micrograms per liter would have resulted in phosphorus limitation (an N/P ratio >14/1).

C. Nutrient Controllability:

1. Point sources--During the sampling year, Lake Memphremagog received a total phosphorus load at a rate less than that proposed by Vollenweider (in press) as "dangerous" (i.e., a eutrophic rate; see page 22) but well in excess of his "permissible" or oligotrophic rate. Of this load, it is calculated that Vermont point sources contributed about 42%. The amount of phosphorus contributed by Quebec point sources is not known, but if these sources contributed only 0.7 lbs/acre/yr (0.08 $g/m^2/yr$), a dangerous loading rate would have resulted.

It is concluded that 80 to 90 percent removal of phosphorus at Vermont and Quebec point sources would reduce the loading to a rate approximating an oligotrophic rate and should result in a marked improvement in the trophic condition of the Vermont portion of Lake Memphremagog as well as provide adequate protection of the existing water quality elsewhere in the lake.

2. Non-point sources--The mean annual phosphorus exports of the Clyde and Johns rivers compared favorably with the exports

of unimpacted Vermont streams studied elsewhere (see pages 21 and 24), but the mean phosphorus exports of the Barton and Black rivers were significantly higher. These higher exports are believed to be due to more intensive agricultural uses in the Barton and Black river drainages and perhaps also to the extensive wetlands adjacent to these two streams.

II. INTRODUCTION

Among the 220-plus water bodies included in the National Eutrophication Survey in 1972, Lake Memphremagog is unique in that 73 percent of the lake area and 91 percent of the lake volume are in the Province of Quebec, Canada; and, therefore, only a very small portion of this water body was subject to study during the Survey. Because of this, reliance on the lake data obtained by other investigators has been necessary in the assessment of trophic conditions elsewhere in the lake. Conversely, 71 percent of the Memphremagog drainage basin is in Vermont, and the Survey assessment of point and areal sources of nutrients to the lake is much more complete. However, little is known about Quebec sources of nutrients.

Recreational uses of Lake Memphremagog include fishing, boating, swimming, and aesthetics. The lake is also used as a water supply for camps and resorts along the shores.

Fishing is reported to be excellent in the Vermont portion, particularly for rainbow trout in spring and early summer and for brown trout in the fall (Clough, 1973). Fishing for landlocked salmon formerly was excellent, but the construction of dams on the major spawning streams, particularly the Clyde River, has virtually eliminated this fishery in the Vermont part of the lake. Residual populations of salmon are still found in the Quebec portion of the lake, and fishing for the deep-water lake trout continues to be good there.

By international treaty, water level fluctuations are maintained within specific limits by the operation of the Dominion Textile Company, Ltd., hydroelectric dam at Magog, Quebec, Canada.

III. LAKE AND DRAINAGE BASIN CHARACTERISTICS

A. Lake Morphometry*:

1. Entire Lake -

   a. Surface area: 23,369 acres.

   b. Mean depth: 51 feet.

   c. Maximum depth: 351 feet.

   d. Volume: 1,191,819 acre/feet.

   e. Mean hydraulic retention time: 1.7 years.

2. U. S. Portion -

   a. Surface area: 6,269 acres.

   b. Mean depth: 21 feet.

   c. Maximum depth: 39 feet.

   d. Volume: 131,649 acre/feet.

   e. Mean hydraulic retention time: 0.26 years.

B. Tributaries and Outlet:
(See Appendix A for U.S. flow data)

1. Tributaries in U.S. -

	Drainage area†	Mean flow†
Barton River	174.0 mi^2	237.6 cfs
Black River	134.0 mi^2	204.1 cfs
Clyde River	142.0 mi^2	216.1 cfs
Johns River	9.9 mi^2	15.0 cfs
Minor tributaries & immediate drainage in Vermont	17.2 mi^2	26.2 cfs††

* Morse and Flanders, 1971.

† Drainage areas are accurate within ±1%; gaged flows are accurate within ±15%, and ungaged flows are accurate within ±20%.

†† Estimated using the runoff coefficient used by U.S.G.S. in determining major U.S. tributary flows.

	Drainage area†	Mean flow†
2. All tributaries & immediate drainage in Quebec	173.4 mi^2	264.0 cfs††
Totals	650.5 mi^2	963.0 cfs
3. Outlet (in Quebec) - Magog River	687.0 mi^2*	963.0 cfs

C. Precipitation**:

1. Year of sampling: 47.4 inches.
2. Mean annual: 36.9 inches.

† Drainage areas are accurate within ±1%; gaged flows are accurate within ±15%, and ungaged flows are accurate within ±20%.
†† Estimated using the runoff coefficient used by U.S.G.S. in determining major U.S. tributary flows.
* Includes area of lake.
** See Working Paper No.1, "Survey Methods".

IV. LAKE WATER QUALITY SUMMARY

Lake Memphremagog was sampled three times during the open-water season of 1972 by means of a pontoon-equipped Huey helicopter. Each time, samples for physical and chemical parameters were collected from three stations on the lake and from a number of depths at each station (see map, page v), except for station 3 at which the July sample could not be collected because of a helicopter fuel shortage. During each visit, a single depth-integrated (15 feet or near bottom to surface) sample was composited from the stations for phytoplankton identification and enumeration, and a depth-integrated sample was collected from each of the stations for chlorophyll a analysis. The maximum depths sampled were 30 feet at station 1, 7 feet at station 2, and 24 feet at station 3.

During the October, 1972 sampling period, a single five-gallon depth-integrated sample was composited from the three stations for algal assays; however, this sample was lost in shipment, and a similar sample was provided by personnel of the Vermont Department of Water Resources in May of 1973.

The results obtained are presented in full in Appendix B, and the data for the fall sampling period, when the lake was essentially well-mixed, are summarized below. Note, however, the Secchi disc summary is based on all values.

For differences in the various parameters at the other sampling times, refer to Appendix B.

A. Physical and chemical characteristics:

Parameter	Minimum	Mean	Median	Maximum
		FALL VALUES (10/05/72)		
Temperature (Cent.)	13.8	13.9	13.9	14.0
Dissolved oxygen (mg/l)	9.2	9.7	9.8	10.2
Conductivity (μmhos)	138	175	164	228
pH (units)	7.3	7.5	7.5	7.8
Alkalinity (mg/l)	28	62	62	96
Total P (mg/l)	0.015	0.030	0.021	0.060
Dissolved P (mg/l)	0.006	0.012	0.008	0.027
NO_2 + NO_3 (mg/l)	0.010	0.029	0.025	0.050
Ammonia (mg/l)	0.030	0.057	0.055	0.100
		ALL VALUES		
Secchi disc (inches)	60	78	79	100

B. Biological characteristics:

1. Phytoplankton -

Sampling Date	Dominant Genera	Number per ml
06/03/72	1. Dinobryon	1,092
	2. Fragilaria	1,005
	3. Anabaena	260
	4. Asterionella	202
	5. Melosira	159
	Other genera	124
	Total	2,842
07/31/72	1. Dinobryon	1,036
	2. Fragilaria	325
	3. Cryptomonas	277
	4. Polycystis	169
	5. Rhizosolenia	157
	Other genera	795
	Total	2,759
10/05/72	1. Anabaena	3,057
	2. Melosira	943
	3. Flagellates	906
	4. Synedra	717
	5. Chroococcus	340
	Other genera	1,622
	Total	7,585

2. Chlorophyll a -
(Because of instrumentation problems during the 1972 sampling, the following values may be in error by plus or minus 20 percent.)

Sampling Date	Station Number	Chlorophyll a (µg/l)
06/03/72	01	16.6
	02	13.8
	03	7.8
07/31/72	01	17.1
	02	17.9
	03	(not done)
10/05/72	01	3.3
	02	11.0
	03	24.5

C. Limiting Nutrient Study:

1. Autoclaved, filtered, and nutrient spiked -

Spike (mg/l)	Ortho P Conc. (mg/l)	Inorganic N Conc. (mg/l)	Maximum yield (mg/l-dry wt.)
Control	0.012	0.300	2.5
0.010 P	0.022	0.300	5.1
0.020 P	0.032	0.300	6.3
0.050 P	0.062	0.300	6.7
0.050 P + 5.0 N	0.062	5.300	18.5
0.050 P + 10.0 N	0.062	10.300	21.1
10.0 N	0.012	10.300	1.6

2. Filtered and nutrient spiked -

Spike (mg/l)	Ortho P Conc. (mg/l)	Inorganic N Conc. (mg/l)	Maximum yield (mg/l-dry wt.)
Control	0.009	0.250	1.4
0.010 P	0.019	0.250	3.8
0.020 P	0.029	0.250	4.8
0.050 P	0.059	0.250	5.5
0.050 P + 5.0 N	0.059	5.250	12.4
0.050 P + 10.0 N	0.059	10.250	13.4
10.0 N	0.009	10.250	1.1

3. Discussion -

The control yields of the assay alga, Selenastrum capricornutum, show that the potential primary productivity of the Vermont portion of Lake Memphremagog was moderate at the time the sample was collected (May, 1973). Also, the significantly increased yields with increased levels of orthophosphorus (to about 0.030 mg/l) show that the lake was phosphorus limited (note that the addition of only nitrogen produced yields no greater than the control yields).

The 1972 lake data indicate phosphorus limitation in the Vermont portion of the lake in June (N/P ratio - 36/1) but nitrogen limitation in July (N/P = 11/1) and October (N/P = 7/1) of that year.

It may be questioned whether point-source phosphorus control would be effective when at least the Vermont portion of the lake may be nitrogen limited at times. Note, however, that in October, 1972, when the N/P ratio was 7/1, a reduction in mean dissolved phosphorus of only 6 micrograms per liter would have resulted in phosphorus limitation (N/P ratio >14/1); and likewise, a reduction of only 4 µg/l in July would have resulted in phosphorus limitation (N/P = 14/1).

D. Trophic Condition:

The increasing occurrence of troublesome blooms of blue-green algae is the best indication of the eutrophic state of the Vermont portion of the lake. The Survey data support this assessment in that mean chlorophyll *a* and mean total phosphorus values for the Vermont portion of the lake are the highest of all Vermont water bodies studied, including Lake Champlain. Studies previously conducted by personnel of the Vermont Department of Water Resources (Morse and Flanders, 1971) support this conclusion.

V. NUTRIENT LOADINGS
(See Appendix C for data)

For the determination of nutrient loadings, the Vermont National Guard collected monthly near-surface grab samples from each of the tributary sites indicated on the map (page v), except for the high runoff months of April and May when two samples were collected. Sampling was begun in July, 1972, and was completed in July, 1973.

Through an interagency agreement, stream flow estimates for the year of sampling and a "normalized" or average year were provided by the New England District Office of the U.S. Geological Survey for the Vermont tributary sites nearest the lake.

In this report, nutrient loads for sampled Vermont tributaries were calculated using mean annual concentrations and mean annual flows. Nutrient loadings for unsampled Vermont "minor tributaries and immediate drainage" ("ZZ" of U.S.G.S) and Quebec tributaries and immediate drainage were estimated by using the nutrient loads, in lbs/mi^2/year, in the Johns River at station 51 and multiplying by the respective Vermont ZZ and Quebec drainage areas in mi^2.

The operator of the Newport wastewater treatment plant provided monthly effluent samples and corresponding flow data; however, the untreated discharges of the villages of Albany, Barton, Derby Center, Glover, Island Pond, and Orleans were not sampled during the Survey, and

nutrient loads attributed to these sources were estimated*. Nutrient contributions from Quebec point sources are not known.

The wastes from the villages of Derby Center and Island Pond are intercepted by Clyde Pond, and the estimated nutrient loads attributed to these two sources were adjusted for the calculated retention in Clyde Pond (15% of the phosphorus and none of the nitrogen; see Working Paper No. 15, "Report on Clyde Pond").

In this report, the nutrient loads attributed to the various tributaries are those measured at the respective sampling stations minus upstream point-source loads, if any. Note, however, that the Clyde River loads were measured at station 22 upstream from the Newport discharge, and only the loads attributed to the villages of Derby Center and Island Pond were subtracted from the measured Clyde Pond loads.

The total phosphorus outlet load in the Magog River in Quebec was estimated on the basis of phosphorus data obtained in a study by personnel of the Vermont Department of Water Resources (Morse and Flanders, op. cit.; at their station 19) and the estimated outlet flow. Comparable data for nitrogen were not available, and no estimate of the outlet nitrogen load could be made.

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* See Working Paper No. 1, "Survey Methods".

A. Waste Sources:

1. Known Vermont municipal -

Name	Pop. Served*	Treatment	Mean Flow (mgd)	Receiving Water
Newport	5,000	primary	1.361	Clyde River
Derby Center	430	none	0.043*	Clyde River
Island Pond	300	none	0.030*	Cylde River
Barton	1,170	none	0.117*	Barton River
Glover	240	none	0.024*	Barton River
Orleans	1,890	none	0.189*	Barton River
Albany	120	none	0.012*	Black River

2. Vermont industrial - There are no known separate industrial discharges of nutrient significance.

* Estimated; see Working Paper No. 1, "Survey Methods".

B. Annual Total Phosphorus Loading - Average Year:

1. Inputs -

Source	lbs P/ yr	% of total
a. Vermont tributaries (non-point load) -		
Barton River	19,780	18.8
Black River	16,050	15.2
Clyde River	9,850	9.4
Johns River	560	0.5
b. Minor tributaries & immediate drainage in Vermont (non-point load) -	980	0.9
c. All tributaries & immediate drainage in Quebec (non-point load) -	9,880	9.4
d. Known Vermont municipal -		
Newport STP	30,470	29.0
Derby Center	1,280	1.2
Island Pond	360	0.3
Barton	4,100	3.9
Glover	840	0.8
Orleans	6,620	6.3
Albany	420	0.4
e. Septic tanks (entire lake)* -	380	0.4
f. Known industrial - None	-	-
g. Direct precipitation (entire lake)** -	3,650	3.5
Total	105,220	100.0

* Estimated 1,500 persons served; see Working Paper No. 1.
** Estimated; see Working Paper No. 1.

2. Outputs -

Magog River, Quebec	60,670*

3. Net annual P accumulation - 44,550 pounds

* Estimated; see page 15.

C. Annual Total Nitrogen Loading - Average Year:

1. Inputs -

Source	lbs N/ yr	% of total
a. Vermont tributaries (non-point load) -		
Barton River	483,490	20.8
Black River	432,010	18.6
Clyde River	385,430	16.6
Johns River	32,690	1.4
b. Minor tributaries & immediate drainage in Vermont (non-point load) -	56,790	2.4
c. All tributaries & immediate drainage in Quebec (non-point load) -	572,570	24.6
d. Known Vermont municipal -		
Newport STP	84,300	3.6
Derby Center	4,040	0.2
Island Pond	2,540	0.1
Barton	11,000	0.5
Glover	2,260	<0.1
Orleans	17,770	0.8
Albany	1,130	<0.1
e. Septic tanks (entire lake)* -	14,100	0.6
f. Known industrial - None	-	-
g. Direct precipitation (entire lake)** -	225,140	9.7
Total	2,325,260	100.0

* Estimated 1,500 persons served; see Working Paper No. 1.
** Estimated; see Working Paper No. 1.

2. Outputs -

   Magog River, Quebec Unknown

3. Net annual N accumulation - Unknown

D. Mean Annual Non-point Nutrient Export by Subdrainage Area:

Tributary	lbs $P/mi^2/yr$	lbs $N/mi^2/yr$
Barton River	114	2,779
Black River	120	3,224
Clyde River	69	2,714
Johns River	57	3,302

E. Yearly Loading Rates - Entire Lake:

In the following table, the existing phosphorus loading rates, exclusive of Quebec point sources, are compared to those proposed by Vollenweider (in press). Essentially, his "dangerous" rate is the rate at which the receiving waters would become eutrophic or remain eutrophic; his "permissible" rate is that which would result in the receiving water remaining oligotrophic or becoming oligotrophic if morphometry permitted. A mesotrophic rate would be considered one between "dangerous" and "permissible".

	Total Phosphorus		Total Nitrogen	
Units	Total	Accumulated	Total	Accumulated
lbs/acre/yr	4.5	1.9	99.5	?
grams/m^2/yr	0.50	0.21	11.2	-

Vollenweider loading rates for phosphorus ($g/m^2/yr$) based on mean depth and mean hydraulic retention time of Lake Memphremagog:

"Dangerous" (eutrophic rate)	0.58
"Permissible" (oligotrophic rate)	0.29

F. Controllability of Nutrients:

1. Point sources--During the Survey sampling year, Lake Memphremagog received a total phosphorus load at a rate a little less than Vollenweider's dangerous rate but well in excess of the permissible rate. Of this load, it is calculated that Vermont point sources contributed about 42%. The amount of phosphorus contributed by Quebec point sources is not known, but note that if these sources contributed only 0.7 lbs/acre/yr, or 0.08 $g/m^2/yr$, a dangerous loading rate would have resulted.

In the following table, the total phosphorus loading rates that can be achieved by the specified levels of phosphorus removal at the seven Vermont point sources are compared to Vollenweider's suggested rates.

% of P Removal	Total P Loading, lbs/acre/yr	Total P Loading, $g/m^2/yr$
Existing	4.5	0.50
50	3.6	0.40
70	3.2	0.36
80	3.0	0.34
90	2.8	0.31
100	2.6	0.29
Vollenweider:		
"Dangerous" (eutrophic rate)		0.58
"Permissible" (oligotrophic rate)		0.29

It is evident that any of the indicated levels of phosphorus removal would significantly reduce the loading rate, but only complete removal would result in a permissible or oligotrophic rate.

As noted before, the existing phosphorus loading rate does not account for Quebec point-source loads. Had these loads been included, the loading rate would have been higher to some degree, of course, and it follows that phosphorus reduction at Quebec point sources comparable to that provided at Vermont point sources would be necessary to achieve a favorable loading rate.

It is quite unlikely that the 100 percent removal of phosphorus required to reduce the calculated loading rate to the permissible or oligotrophic rate is feasible or even possible. However, 80 to 90 percent removal would approximate the oligotrophic rate and should result in a marked improvement in the trophic condition of the Vermont portion of Lake Memphremagog as well as provide adequate protection of existing water quality elsewhere in the lake.

Previous studies (Morse and Flanders, op. cit.) have shown that, except for Fitch Bay in Quebec, aerobic conditions persist throughout the lake in even the deepest portions; and, therefore,

recycling of sedimented phosphorus should be minimal. This should enhance the effectiveness of phosphorus removal at the levels suggested above.

At the time of preparation of this report, active planning for phosphorus removal at the City of Newport is underway; plans have been approved for treatment facilities at the villages of Island Pond (Brighton Town) and Orleans; preliminary engineering plans have been approved for the villages of Albany, Barton, and Derby Center; and a regional waste treatment facility to serve the villages of Barton, Glover, and Orleans is still under active consideration by the Vermont Agency of Environmental Conservation (Morse, 1974). Phosphorus removal ultimately will be provided at each of these waste-treatment facilities, but timing is dependent on other construction priorities and availability of construction grant funds (Clough, 1974).

2. Non-point sources--During the Survey sampling year, the mean annual phosphorus exports of the Clyde River and the Johns River (see page 21) compared favorably with the exports of unimpacted Vermont streams studied elsewhere in which the mean phosphorus export was 52 lbs/mi^2/yr and the range was from 30 to 65 lbs/mi^2/yr.

In part, the relatively low Clyde River export probably is due to the ponds and lakes in the course of the river in which

sedimentation and/or biological assimilation of phosphorus can occur, while the low export of the Johns River is likely due to the small watershed and comparative lack of cultural influences.

The significantly higher mean phosphorus exports of the Barton and Black rivers may have been due to underestimation of point-sources loads. However, the only point source known in the Black River drainage is the small community of Albany (estimated contributing population of 120), and it is hardly conceivable that underestimation of that load resulted in the higher export attributed to the Black River. It is much more likely that the higher phosphorus export of these two rivers is due to the more intensive agricultural uses in the drainages and perhaps also the occurrence of extensive wetlands adjacent to both streams, particularly in the Black River system.

VI. LITERATURE REVIEWED

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Ketelle, Martha J., and Paul D. Uttormark, 1971. Problem lakes in the United States. EPA Water Poll. Contr. Res. Ser., Proj. 16010 EHR, Wash., D.C.

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VII. APPENDICES

APPENDIX A

TRIBUTARY FLOW DATA

TRIBUTARY FLOW INFORMATION FOR VERMONT 8/8/74

LAKE CODE 5008 LAKE MEMPHREMAGOG

TOTAL DRAINAGE AREA OF LAKE 0.0

NORMALIZED FLOWS

TRIBUTARY	SUB-DRAINAGE AREA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
500822	17.20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
500823	142.00	120.00	116.00	237.00	843.00	305.00	160.00	91.70	94.80	96.40	148.00	204.00	182.00	216.12
500831	174.00	132.00	127.00	261.00	927.00	335.00	176.00	101.00	104.00	106.00	162.00	225.00	200.00	237.59
500841	134.00	114.00	109.00	224.00	796.00	288.00	151.00	86.60	89.50	91.10	139.00	193.00	172.00	204.09
500851	9.87	8.37	8.05	16.50	58.60	21.20	11.20	6.38	6.59	6.71	10.30	14.20	12.60	15.03

SUMMARY

TOTAL DRAINAGE AREA OF LAKE = 0.0
SUM OF SUB-DRAINAGE AREAS = 477.07

TOTAL FLOW IN = 8087.77
TOTAL FLOW OUT = 0.0

NOTE *** TOTAL DRAINAGE AREA OF LAKE AND DATA FOR TRIB ZZ NOT KNOWN

MEAN MONTHLY FLOWS AND DAILY FLOWS

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
500823	7	72	194.00	15	116.00				
	8	72	132.00	12	126.00				
	9	72	55.80	19	49.00				
	10	72	102.00	15	75.80				
	11	72	221.00	9	577.00				
	12	72	207.00	7	602.00				
	1	73	241.00	24	849.00				
	2	73	202.00	21	141.00				
	3	73	499.00	21	802.00				
	4	73	623.00	17	674.00	23	581.00		
	5	73	482.00	6	503.00	23	1035.00		
	6	73	359.00						
	7	73	466.00	7	604.00				
500831	7	72	214.00	15	128.00				
	8	72	145.00	12	138.00				
	9	72	61.50	19	53.70				
	10	72	112.00	15	83.10				
	11	72	243.00	9	633.00				
	12	72	228.00	7	663.00				
	1	73	264.00	24	933.00				
	2	73	222.00	21	155.00				
	3	73	548.00	21	880.00				
	4	73	685.00	17	741.00	23	638.00		
	5	73	529.00	5	580.00	23	1137.00		
	6	73	394.00						
	7	73	513.00	6	744.00				

TRIBUTARY FLOW INFORMATION FOR VERMONT 8/8/74

LAKE CODE 500A LAKE MEMPHREMAGOG

MEAN MONTHLY FLOWS AND DAILY FLOWS

TRIBUTARY	MONTH	YEAR	MEAN FLOW	DAY	FLOW	DAY	FLOW	DAY	FLOW
500A41	7	72	184.00	15	110.00				
	8	72	124.00	12	119.00				
	9	72	52.80	19	46.10				
	10	72	96.20	15	71.40				
	11	72	208.00	9	544.00				
	12	72	196.00	7	570.00				
	1	73	228.00	24	801.00				
	2	73	191.00	21	133.00				
	3	73	470.00	21	756.00				
	4	73	588.00	17	636.00	23	548.00		
	5	73	455.00	5	498.00	23	977.00		
	6	73	338.00						
	7	73	440.00	6	639.00				
500A51	7	72	13.50	15	8.10				
	8	72	9.20	12	8.70				
	9	72	3.90	19	3.40				
	10	72	7.10	15	5.30				
	11	72	15.30	9	40.10				
	12	72	14.40	7	41.90				
	1	73	16.70	24	59.00				
	2	73	14.10	21	9.80				
	3	73	34.60	21	55.70				
	4	73	43.30	17	46.90	23	40.40		
	5	73	33.50	6	34.90	23	72.00		
	6	73	25.10						
	7	73	32.40	7	42.00				

APPENDIX B

PHYSICAL and CHEMICAL DATA

J* Value known to be in error

K* Value known to be less than indicated

STORET RETRIEVAL DATE 74/07/02

500=01
** SS 30.0 272 11 00.0
LAKE ERIE-MAGO
50 VERMONT

115MALES 211202
5 CODE FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00630 NO2&NO3 N-TOTAL MG/L	00610 NH3-N TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P
72/06/03	17	25 0000	18.1	11.2	100	120	7.80	43	0.190	0.020	0.010	0.003
	17	25 0010	11.6	11.1		120	7.70	43	0.190	0.010	0.005	0.003
	17	25 0020	9.5	10.4		120	7.40	40	0.220	0.040	0.011	0.005
	17	25 0030	6.4	9.8		120	7.20	43	0.240	0.010K*	0.009	0.004
72/07/31	17	00 0000			76	175	7.80	61	0.040	0.030	0.014	0.010
	17	00 0005	21.6	8.4		175	7.40	61	0.100	0.070	0.016	0.011
72/10/05	10	20 0000			84	228	7.50	46	0.030	0.060	0.020	0.007
	10	20 0004	14.0	9.8		228	7.50	43	0.030	0.040	0.029	0.004

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/06/03	17	25 0000	16.6J*
72/07/31	17	00 0000	17.1J
72/10/05	10	20 0000	3.3J

J* Value known to be in error
K* Value known to be less than indicated

STORET RETRIEVAL DATE 74/07/02

50002
44 56 30.6 072 13 00.
LAKE MEMPHREMAGOG
50019 VERMONT

11PALES 2111202
5 0006 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00630 NO2&NO3 N-TOTAL MG/L	00610 NH3-N TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P
72/06/03	18 00	0000	18.3	10.2	90	160	8.00	64	0.040	0.020	0.027	0.005
	18 00	0007	13.7	10.5		140	7.70	52	0.160	0.020	0.024	0.006
72/07/31	16 40	0000			72	160	7.50	60	0.070	0.100	0.042	0.028
	16 40	0005	22.9			160	7.50	49	0.080	0.080	0.036	0.016
72/10/05	10 10	0000			60	190	7.30	77	0.050	0.100	0.050	0.027
	10 10	0004	13.9	9.2		200	7.30	72	0.050	0.090	0.040	0.025

32A

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/06/03	18 00	0000	13.8J
72/07/31	16 40	0000	17.9J
72/10/05	10 10	0000	11.0J

STORET RETRIEVAL DATE 74/07/02

500803
44 58 30.0 072 13 30.0
MEMPHREMAGOG LAKE
50019 VERMONT

11ERALES 2111202
5 0009 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00010 WATER TEMP CENT	00300 DO MG/L	00077 TRANSP SECCHI INCHES	00094 CNDUCTVY FIELD MICROMHO	00400 PH SU	00410 T ALK CACO3 MG/L	00630 NO2&NO3 N-TOTAL MG/L	00610 NH3-N TOTAL MG/L	00665 PHOS-TOT MG/L P	00666 PHOS-DIS MG/L P
72/06/03	18 15	0000	17.7	9.5	82	180	8.10	61	0.090	0.010	0.014	0.003
	18 15	0006	18.3	9.7		170	8.00	60	0.100	0.040	0.024	0.003
72/10/05	09 50	0000			60	138	7.75	52	0.020	0.050	0.022	0.009
	09 50	0004	14.0	10.2		138	7.75	50	0.020	0.060	0.015	0.009
	09 50	0015	13.9	10.0		138	7.70	28	0.010	0.030	0.026	0.006
	09 50	0024	13.8	9.4		138	7.40	28	0.020	0.030	0.018	0.006

33
A

DATE FROM TO	TIME OF DAY	DEPTH FEET	32217 CHLRPHYL A UG/L
72/06/03	18 15	0000	7.8J
72/10/05	09 50	0000	24.5J

APPENDIX C

TRIBUTARY and WASTEWATER
TREATMENT PLANT DATA

K* Value known to be less than indicated

STORET RETRIEVAL DATE 74/07/02

S00822 LS500822
44 56 30.0 072 11 30.0
CLYDE RIVER
50 15/MEMPHREMOGOG
1/LAKE MEMPHREMAGOG
BRDG BELO GAGE STN ABOV NEWPORT STP
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/07/15	10 35		0.093	0.400	0.020	0.010	0.020
72/08/12	10 56		0.062	0.500	0.010	0.005K*	0.032
72/09/19	10 10		0.121	0.600	0.076	0.007	0.024
72/10/15	12 10		0.180	0.450	0.092	0.005K	0.028
72/11/09	12 15		0.200	0.660	0.044	0.010	0.063
72/12/07	09 45		0.250	0.290	0.026	0.008	0.011
73/01/24	10 35		0.410	0.500	0.056	0.010	0.045
73/02/21	09 25		0.399	0.480	0.154	0.006	0.015
73/03/21	10 25		0.360	0.960	0.370	0.008	0.035
73/04/17	10 10		0.280	0.330	0.034	0.005K	0.020
73/04/23	14 05		0.240	1.150	0.030	0.005K	0.015
73/05/06	09 45		0.198	0.360	0.034	0.005K	0.025
73/05/23	11 00		0.189	0.400	0.036	0.007	0.025
73/07/07	10 00		0.110	2.510	1.630	0.005K	0.025

K* Value known to be less than indicated

STORET RETRIEVAL DATE 74/07/02

S00823 LS500823
44 56 30.0 072 12 30.0
CLYDE RIVER
50 15/MEMPHREMAGOG
I/LAKE MEMPHREMAGOG
AT GLEN ROAD BRDG BELOWNEWPORT STP
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/07/15	10	19	0.019	0.450	0.017	0.009	0.029
72/08/12	10	47	0.020	0.650	0.010	0.005K	0.038
72/09/19	10	00	0.048	1.050	0.074	0.017	0.052
72/10/15	12	05	0.117	0.500	0.105	0.007	0.048
72/11/09	12	10	0.182	0.660	0.052	0.008	0.026
72/12/07	09	40	0.310	0.360	0.037	0.008	0.015
73/01/24	10	40	0.370	0.750	0.260	0.014	0.030
73/03/21	10	35	0.370	0.355	0.078	0.005K	0.020
73/04/17	10	00	0.320	0.350	0.050	0.006	0.025
73/04/23	14	00	0.180	0.480	0.024	0.006	0.025
73/05/06	10	40	0.168	0.330	0.029	0.005K	0.035
73/05/23	10	00	0.130	0.560	0.030	0.010	0.040
73/07/07	09	20	0.120	2.300	1.700	0.019	0.030

36
A

STORET RETRIEVAL DATE 74/07/02

500831 LS500831
44 52 30.0 072 12 00.0
BARTON RIVER
50 15/MEMPHREMAGOG
I/LAKE MEMPHREMAGOG
COVENTRY STATION BRDG
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/07/15	10 57		0.185	0.300	0.036	0.015	0.038
72/08/12	10 27		0.143	0.760	0.039	0.017	0.060
72/09/19	09 48		0.290	0.500	0.080	0.014	0.052
72/10/15	11 40		0.182	0.400	0.097	0.013	0.039
72/11/09	11 55		0.234	0.860	0.069	0.016	0.210
72/12/07	09 20		0.410	0.720	0.066	0.026	0.176
73/01/24	10 15		0.370	0.690	0.170	0.014	0.055
73/03/21	10 00		0.400	0.520	0.130	0.006	0.035
73/04/17	10 50		0.294	0.630	0.082	0.007	0.035
73/04/23	13 20		0.230	1.150	0.029	0.009	0.045
73/05/05	09 00		0.250	2.000	0.080	0.008	0.035
73/05/23	10 00		0.110	1.200	0.126	0.014	0.050
73/07/06	08 20		0.150	1.320	0.690	0.011	0.040

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STORET RETRIEVAL DATE 74/07/02

500841 LS500841
44 55 10.0 072 13 30.0
BLACK RIVER
50 15/MEMPHREMAGOG
I/LAKE MEMPHREMAGOG
NEWPORT AIRPORT RD BRDG
11EPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/07/15	12 39		0.114	0.650	0.040	0.009	0.038
72/09/19	09 50		0.100	0.500	0.056	0.010	0.030
72/10/15	11 45		0.182	0.350	0.075	0.005K	0.021
72/11/09	12 05		0.234	0.650	0.061	0.011	0.056
73/01/24	10 05		0.360	0.540	0.046	0.014	0.065
73/03/21	10 15		0.430	0.820	0.252	0.008	0.030
73/04/17	10 30		0.270	0.500	0.054	0.007	0.055
73/04/23	13 45		0.230	2.200	0.063	0.005K	0.025
73/05/05	10 50		0.168	1.180	0.048	0.008	0.041
73/05/23	10 15		0.120	0.460	0.060	0.019	0.050
73/07/06	09 00		0.115	1.680	0.860	0.007	0.040

STORET RETRIEVAL DATE 74/07/02

S00851 LS500851
44 59 30.0 072 11 00.0
JOHNS RIVER
50 1S/MEMPHREMAGOG
T/LAKE MEMPHREMAGOG
CULVERT E OF QUEBEC CENTRALRR BRDG
11FPALES 2111204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P
72/07/15	13	51	0.411	0.400	0.024	0.014	0.019
72/08/12	11	55	0.460	0.530	0.033	0.005K	0.023
72/10/15	13	18	0.590	0.300	0.088	0.006	0.019
72/11/09	13	30	0.450	0.690	0.078	0.022	0.139
73/01/24	07	30	0.740	0.920	0.330	0.009	0.030
73/03/21	07	30	1.200	0.520	0.150	0.007	0.015
73/04/17	07	30	0.580	0.690	0.210	0.005K	0.015
73/04/23	13	30	0.670	0.310	0.038	0.005K	0.010
73/05/06	11	30	0.590	0.230	0.015	0.005K	0.015
73/05/23	09	30	0.440	0.460	0.020	0.011	0.020
73/07/07	07	00	0.580	0.420	0.080	0.008	0.025

STORET RETRIEVAL DATE 74/09/04

5008S1 PR5008S1 P005000
44 56 30.0 072 12 00.0
NEWPORT
50 15 MEMPHREMAGOG
T/MEMPHREMAGOG
CLYDE RIVER
11EPALES 2141204
4 0000 FEET DEPTH

DATE FROM TO	TIME OF DAY	DEPTH FEET	00630 NO2&NO3 N-TOTAL MG/L	00625 TOT KJEL N MG/L	00610 NH3-N TOTAL MG/L	00671 PHOS-DIS ORTHO MG/L P	00665 PHOS-TOT MG/L P	50051 FLOW RATE INST MGD	50053 CONDUIT FLOW-MGD MONTHLY
73/02/06	08 00								
CP(T)-			0.350	21.000	4.000	2.800	7.300	1.230	1.200
73/02/06	16 00								
73/04/23	08 00								
CP(T)-			0.330	26.000	4.700	3.500	8.500	1.160	1.200
73/04/23	16 00								
73/09/18			0.220	26.200	4.200	8.100	12.500	1.330	1.140
73/09/21			0.189	29.700	3.700	3.100	7.500	1.220	1.210
73/10/17	08 00								
CP(T)-			0.189	17.000	0.287	6.600	9.800	1.190	1.060
73/10/17	16 00								
73/11/06			0.110	26.000	4.000	6.800	10.500	1.170	1.120
73/11/21	08 00								
CP(T)-			0.120	22.000	2.900	4.900	8.600	1.030	1.090
73/11/21	14 00								
73/12/13			0.240	19.500	1.500	5.600	9.400	1.090	1.360
74/02/26	07 45		0.400	20.000	1.000	6.000	7.400	1.450	1.760
74/03/27	16 00		0.240	27.000	4.800	3.500	7.800	1.470	1.400
74/04/24	09 42		0.600	5.200	0.340	0.330	1.100	2.060	1.970
74/05/21	08 35		0.280	13.000	0.490	1.300	3.800	1.790	1.820

CONVERSION FACTORS

acres x 0.4047 = hectares

feet x 0.3048 = meters

acre-feet x 1,233.49 = cubic meters

square miles x 2.590 = square kilometers

cubic feet/second x 0.02832 = cubic meters/second

inches x 2.540 = centimeters

gallons x 3.785 = liters

pounds x 0.45352 = kilograms

pounds/acre/year x 0.112084 = grams/square meter/year